Quantification and Control of Nonpoint Source Pollution of Water Resources to Minimize Health Hazards

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ABSTRACT

Agriculture is the major contributor and victim of nonpoint source (NPS) pollution. Quantification and control of NPS pollutants both at localized and regional scale is of paramount importance to minimize health hazards. The existing models can hardly simulate the surface transport and leaching of NPS pollutants precisely. Keeping these facts in mind, the reported study has a major goal of developing an integrated approach to determine the fate and balance of major agrichemicals and to develop a Decision Support System (DSS) using the results of laboratory, lysimetric, and field studies. The cutoff limit of agrichemical not causing soil and water pollutions was determined through watershed scale study and optimization technique. Lysimetric leaching study revealed that irrigation scheduling based on 10% maximum allowable depletion (MAD) of available soil water (ASW) results in more leaching losses of nutrients than that based on 40% and 60% MAD of ASW. Controlled field experiments revealed that 40% MAD of ASW is the best for scheduling irrigation to maximize yield of major crops. The results of column study with pesticides solutes showed that Malathion degrades faster and leaches slower than Atrazine. Therefore, application of Malathion is considered safer for Indian climates. The developed DSS is of objective nature and can effectively be used for quantification and control of NPS pollution by agrichemicals in a variety of situations.

Keywords: NPS pollution, watershed monitoring, lysimeter, maximum allowable depletion, Decision Support System

1. INTRODUCTION

Nonpoint source pollutants originate from various areas and go into waterways at intervals linked to meteorological events (Novotny & Olem, 1994). Quantification and control of NPS pollution remains relatively a difficult task as compared to the point sources, because the pollutants have no obvious point of entry into receiving watercourses. Agriculture is the greatest contributor among all the sources of water pollutants. Agriculture has been identified as the cause and victim of NPS pollutants in surface water and groundwater (Agrawal, 1999; Donoso, Cancino, & Magri, 1999; Humenik, Smolen, & Dressing, 1987; Li & Zhang, 1999; USEPA, 1994). Agricultural pollutants (e.g., sediment, fertilizers, pesticides, salts, or trace elements) coming from different agricultural practices degrade the surface and groundwater resources in-terms of soil loss, chemical runoff, and leaching. The environmental impact assessment of NPS pollutants at local and regional scale is vital for sustainable agriculture. Therefore, quantification and adoption of management measures are essential to minimize the agricultural NPS pollution of water resources. Adoption of best management practices (BMPs) at watershed or regional scale is the best way to reduce the NPS pollution. The BMPs are methods for controlling NPS pollution and making them compatible with water quality goals (Dillaha, 1996). BMPs can be structural or management oriented (Wolfe, Batchelor, Dillaha, Mostaghimi, & Heatwole, 1995). In solving NPS pollution problems, the BMPs comprising of conservation tillage, improved fertilizer, and animal waste management have been implemented on agricultural land (Anderson & Flaig, 1995; Joelsson & Kyllmar, 2002; Mostaghimi, Park, Cooke, & Wang, 1997). Intensive study on watershed basis is therefore necessary for developing management strategies for abating the agricultural NPS pollution. Hydrologic and water quality investigations are fundamental to any watershed management program. The delineation of watershed parameters is generally carried out using remote sensing data and geographic information system (GIS), whereas mathematical models are used for hydrological evaluation of the watershed and for analysis of water quality issues associated with agricultural activities. Field experiments need to be conducted in farmers' field at the watershed level to measure the loss of agrochemicals and soil through runoff. Controlling the soil and nutrient losses in severe soil erosion areas at watershed scale requires implementation of BMPs. Based on these facts, the reported study was undertaken in controlled field plots of Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur as well as in an agricultural watershed of West Midnapore district, West Bengal with following specific objectives:

1. To estimate the transport of major agrochemicals (fertilizer and pesticides) through runoff and sediments from an agricultural watershed.
2. To assess the balance of agrochemicals in the root zone, crop residue, and leaching beyond the root zone under different methods and scheduling of irrigation through laboratory, lysimetric, and field experiments.
3. To estimate the extent of pollution of soil, ground water, and surface water resources caused by the above-mentioned chemicals.
4. To develop a Decision Support System (DSS) for surface and sub-surface flow and transport processes of water and solute using the results of laboratory, lysimetric, and field studies.

2. METHODOLOGY

2.1 Study area and data monitoring

A small agriculture watershed (namely, Kapgari watershed) situated in the Midnapore district of West Bengal, having an area of 973 ha was selected for the reported study. Based on the drainage network and topography of the watershed, three sub-watersheds have been delineated (Figure 1). For effective monitoring of the NPS pollutants (that is: runoff, sediment and nutrients), gauging stations have been installed at the main outlet of the watershed and outlets of the sub-watersheds.

2.2 Control study in field plots

2.2.1 Experimental site

Field investigations were carried out at the experimental farm of Agricultural and Food Engineering Department, IIT Kharagpur, India. The climate of the study area is sub-humid sub-tropical. The study area receives an average annual rainfall of 1,200 mm, and most of the rainfall occurs during the months of June to October. The predominant soils at the experimental site and the watershed are lateritic with sandy loam texture. The watershed have unmanaged natural resources and is prone to soil erosion due to high-intensity rainfall during monsoon season.

2.2.2 Experiment and crop details

Four crops such as rice, wheat, potato, and peanut were selected for the present study. Wheat, peanut, and potato were grown under unsaturated condition, and rice was grown under saturated condition. Wheat, cultivar Sonalika, is generally a 100–110 days cereal crop and suitable to the climate of the study area during the winter season (December–March). Peanut, cultivar AK-12-24, is a 105–115 days short duration crop with wide adaptability, which was selected for the reported study. Peanut is a popular summer irrigated crop of this region (February–May), which suits to the prevailing climate. Potato, cultivar Kufri-Jyoti, is a popular 90–110 days vegetable crop of the locality, which was selected and suits to the prevailing climate in the winter season (November–February). A total of 36 plots having the size of 5 m × 4 m with a buffer of 1m between adjacent plots were developed in the experimental area. A randomized block design method was used to design the field experiments with treatments as the factors. In this study three irrigation

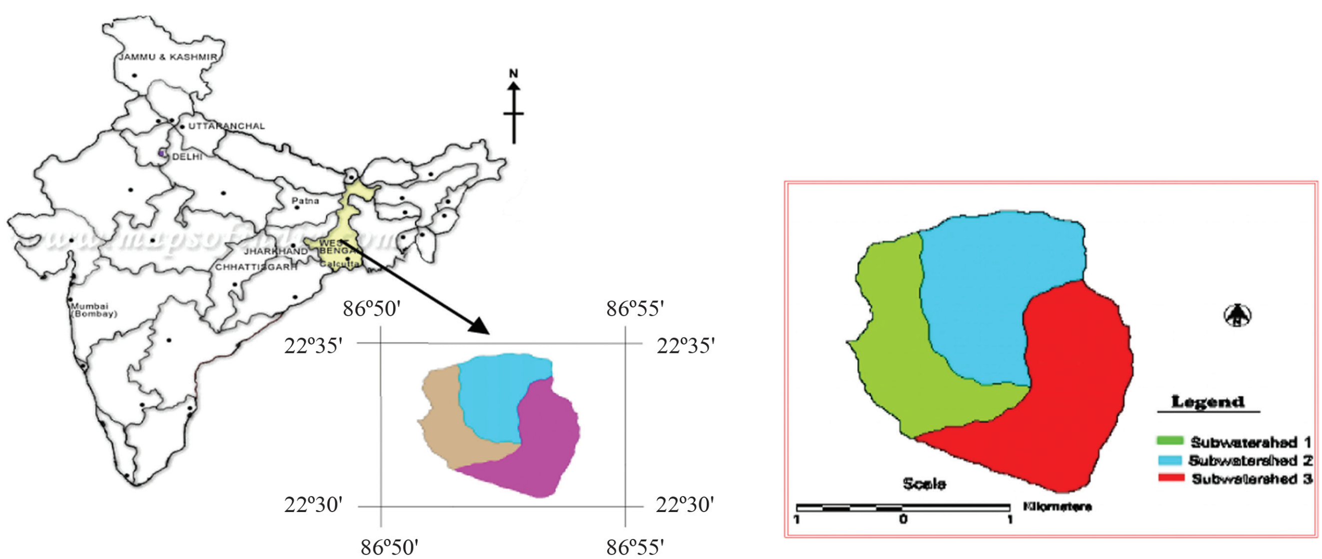

Figure 1. Location map of the Kapgari watershed and delineation of sub-watersheds.

treatments and four fertilizer treatments along with one control treatment were adopted during the field experiments. In order to reduce the uncertainty in measurements, three replications for each treatment were adopted.

A seed rate of 100 kg/ha was used for the wheat crop. The depth of sowing was 5 cm along with row to row and plant to plant spacing of 20 cm and 5 cm respectively. For potato crop, the seeds were sown at a row spacing of 50 cm and a plant spacing of 25 cm during all treatments of the crop experiment. For peanut, a seed rate of 120 kg/ha was used. The seeds were sown at a row spacing of 30 cm and a plant spacing of 20 cm during all the three experiments. For rice, the plant-to-plant and row-to-row spacing were 20 and 15 cm, respectively. From the transplanting to flowering stage, 5 cm depth of ponding was maintained.

2.2.3 Treatments for Irrigation and fertilizer

Irrigation treatments under unsaturated condition for the three crops such as wheat, peanut, and potato were maintained based on the MAD of available soil water criteria, which are as follows:

1. I_1 = 10% maximum allowable depletion (MAD) of available soil water (ASW)
2. I_2 = 40% MAD of ASW
3. I_3 = 60% MAD of ASW

The fertilization treatments during both saturated condition (rice) and unsaturated condition (wheat, potato, and peanut) are as follows:

1. F_1 = fertilizer application of N:P:K as 0:0:0.(same for all crops)
2. F_2 = fertilizer application for N:P:K
   (i) for wheat: 80:40:40 (N:P:K)
   (ii) for potato: 120:100:80 (N:P:K)
   (iii) for peanut: 20:40:40 ((N:P:K)
   (iv) for rice: 80:40:40 (N:P:K)
3. F_3 = fertilizer application for N:P:K
   (i) for wheat: 120:60:60 (N:P:K)
   (ii) for potato: 180:150:120 (N:P:K)
   (iii) for peanut: 30:60:60 (N:P:K)
   (iv) for rice: 120:60:60 (N:P:K)
4. F_4 = fertilizer application for N:P:K
   (i) for wheat: 160:80:80 (N:P:K)
   (ii) for potato: 240:200:160 (N:P:K)
   (iii) for peanut: 40:80:80 (N:P:K)
   (iv) for rice: 80:40:40 (N:P:K)

2.3 Soil and water quality analysis

Soil moisture content and concentration of soluble nutrients were determined through the soil samples at different depths during unsaturated condition of the crop. Each plot has been sampled with three soil samples from each layer, and for each soil layer a merged soil sample was prepared. Further, fifty grams of soil samples were mix-up with 150 g of distilled water and stirred for half an hour with mechanical stirrer. The concentration of NO_3^-, NH_4^+, NO_2^-, K^+, and PO_4^{2-} ions in the filtrate were determined by Ion Chromatography (IC) System. Soil water samples were collected during the rice crop period with the help of soil water samplers at different depths such as: 30 cm, 60 cm and 75 cm to analyze the water quality parameters. Collected soil water samples were analyzed using ion-chromatography system. Nitrate, ammonium, phosphate and potassium were the major form of nutrients analyzed.

2.4 Simulation of solute transport using HYDRUS 2D model

The HYDRUS 2-D was used to study the transport of solute of fertilizers and pesticides applied in the field study.

2.5 Control study in lysimeters

The lysimetric experiments were carried out in the experimental farm. Out of the four lysimeters used in the experiment, wheat was sown in three of them and potato was grown in the fourth one during the year 2004–2005. In these experiments each lysimeter has a cubical shaped soil tank of dimension 85cm × 85cm × 1m rested in the outside tank having dimensions of 87cm × 87cm × 1m. Both the tanks made of mild steel metal sheet were placed on a 15 cm thick concrete platform. Drainage water was collected in the leachate chamber through a pipe (size 12.5 mm) which was connected with the base of the inner tank. A concrete leachate chamber of 1.5m × 1m × 1.5m was constructed for leachete collection from all the four lysimeters. The field soil was used in the lysimeters with same bulk density. Each lysimeter was placed in a plot of 5m×4m size.

2.5.1 Fertilizer and pesticide balance in the lysimeter

For estimating the fertilizer and pesticide balance using lysimeter, following fertilizer, irrigation, and pesticide treatments were selected for wheat and potato crops for unsaturated condition and rice crop for saturated conditions. An irrigation treatment of 10% MAD of ASW was used for wheat and potato crops whereas the fertilizer and pesticide treatments were maintained as follows:

Fertilizer treatment was same as field experiments for Rice, Wheat and Potato.

Pesticide Treatments for Rice and Potato crops

1. P_1 = Malathion 50 EC (i) Rice: @ 1ml/l of water Atrazine 50 WP (ii) Potato: @ 1.5 Kg a.i./ha
2. P_2 = Malathion 50 EC (i) Rice: @ 2 ml/l of water Atrazine 50 WP (ii) Potato: @ 3.5 Kg a.i/ ha
3. P_3 = Malathion 50EC (i) Rice: @ 3 ml/l of water Atrazine 50 WP (ii) Potato: @ 4.5 Kg a.i./ha
4. P_4 = Control

Wheat was sown on 23rd November 2004 in the lysimetric plots followed by a pre-sowing irrigation. The fertilizers doses were applied in two different splits. The leachate was collected, after each irrigation, in high-density PVC sampling buckets. The volume of leachate was immediately measured and analyzed by IC system to determine the nitrate, phosphate and potash. The potato crop in lysimeter was sown on 9th Dec 2004 following a pre-sowing irrigation for easy penetration of tubers. The rice crop in lysimeter was transplanted on 22th July 2005. The herbicide Atrazine was applied as pre-emergence @ 1.5 kg a.i./ha before sowing of potato. Again the fertilizer doses according to the selected treatments were applied in two different splits as basal and topdressing. Similar procedures were followed for leachate collection and analysis as that of wheat. For pesticide detection and quantification IC system with UV detector was used.

2.6 Column study

Experiments in hand packed column were carried out under saturated flow conditions. Columns were constructed of polyacrylic tubes and were of 1m length × 14.5 cm dia. They were packed uniformly with 12 kg soil, which occupied about 65 cm of column. A pre-experimental calibration test showed that the highest flow rate which can maintain unsaturated condition in the soil of experimental farm is 48 cm/day. Hence two flow rates selected for this study were 40 cm/day (lower than the maximum flow rate) and 13 cm/day (1/3rd of the first) for providing detail understanding of water flow effect on transport parameters. Bromide tracer was used in order to characterize the physical transport properties. The columns leached about 4-6 pore volumes of the primary 0.01M KBr solution to achieve desorption by adding nearly four pore volumes of herbicide solution. Effluent flow rate was monitored frequently, and a flow meter was used to record the cumulative volume.

2.6.1 Analysis of sample

The concentration of Malathion and Atrazine was determined by Metrohm modulator, Ion Chromatography/HPLC system. The system was assembled as 762 Isocratic (IC) Interface, 709 IC pump, 733 IC separation center and Lambda 1010 UV/VIS detector operating at UV region of $\lambda = 210$ nm and detector range 1.0 for Malathion and $\lambda = 254$ nm and detector range 1.0 for Atrazine; IC Net 2.1 software (developed by Metrohm AG; Switzerland); RP C-18 column (150 × 4.6mm, 5μm, Prontosil 60-5-C18-H); Mobile phase of acetonitrile (70%) + Water pH 3.5 (30%) for Malathion and 0.025 M.

In this study dipotassium hydrogen phosphate (pH 3.0 with acetic acid) (65%) + acetonitrile (35%) with a flow rate of 1.0 ml/min was applied for Atrazine. The injection volume was 20μl. Malathion test was performed under retention time of 5.2 min and 11.08 min for Atrazine under the chromatographic environment described previously. A quantitative estimation of pesticides was done by using external standards. Analysis was based on average peaks of the external standards. The detection limit was 0.1 mg L^{-1} under the above mentioned chromatographic conditions. Bromide was analyzed by anion column of IC system with a conductivity detector.

2.7 Breakthrough curve data analysis

The experimental effluent Breakthrough Curve (BTC) data were analyzed by moment's solutions method.

For a steady state flow in an uniform medium, the transport equation is

$$R\frac{\partial c}{\partial t} = D\frac{\partial^2}{\partial x^2} - v\frac{\partial c}{\partial x} - \gamma c \qquad (1)$$

Where c is mean volume of concentration (ML^{-3})

D is the dispersion coefficient (L^2T^{-1}),

v is the pore water velocity (LT^{-1}),

x is the distance (L), and t is the time (T) (Gerson and Nir, 1969; van Genutchen and Wagenet, 1989)

Retardation factor R is given by the equation (van Genutchen et al., 1982):

$$\mathrm{R} = 1 + \frac{\rho K_d}{\theta} \qquad (2)$$

The nth temporal moment for a concentration distribution at a location, x, can be defined as

$$M_n = \int_0^\infty t^n c(x,t)\partial t \qquad (3)$$

The nth normalized moment of the distribution can be represented as

$$\mu_n = \frac{M_n}{M_0} = \frac{\int_0^\infty t^n c(x.t)\partial t}{\int_0^\infty c(x,t)\partial t} \qquad (4)$$

The equations (5) and (6) can be utilized for estimation of experimental temporal moments from BTC concentration. By placing experimentally derived moments equal to theoretical moments the parameters R, D, V and λ can be estimated as follows.

$$R = \frac{\mu_1 - 0.5t_{0\sqrt{V^2+4D\lambda}}}{x} \tag{5}$$

$$D = \frac{V^3}{2x}\left(\mu_2 - \mu_1^2 - \frac{t_0^2}{12}\right) \tag{6}$$

$$V = \frac{x}{\mu_1 - 0.5t_0} \tag{7}$$

$$\lambda = \frac{V^2}{4D}\left[\left(1 - \frac{2D}{xV}\ln\frac{M_0}{c_0 t_0}\right) - 1\right] \tag{8}$$

2.8 Optimization module

The optimization module works under the single objective of maximizing yield and reducing nutrient loss through runoff and deep percolation. Basically the module decides the limiting rate of fertilizer application (N and P) that would facilitate a sustainable yield minimizing pollution of surface and ground water.

Objective function:

$$\text{Maximize } Z = a \times (x_1 + x_2 + x_3) + b \tag{9}$$

Where; x_1 = amount of Nitrogen (N) to be applied (kg/ha)

x_2 = amount of Phosphorous (P) to be applied (kg/ha)

a = yield of crop per unit consumption of fertilizer mixture (tons/kg)

b = yield at no application of fertilizers (tons/ha)

Constraints:

(1) Fertilizer constraints in relation to yield

(i) Lower limit of Nutrients

$$x_1 \geq L(\text{N}) \tag{10}$$

$$x_2 \geq L(\text{P}) \tag{11}$$

Where; L (N) = lower limit of N to be applied (kg/ha)

L (P) = lower limit of P to be applied (kg /ha)

(ii) Upper limit of Nutrients:

$$x_1 \leq U(\text{N}) \tag{12}$$

$$x_2 \leq U(\text{P}) \tag{13}$$

Where; U (N) = upper limit of N to be applied (kg/ha)

U (P) = upper limit of P to be applied (kg/ha)

(2) Fertilizer constraints in relation to pollution control

(i) Surface water pollution control

$$NL_R \times (x_1) \leq U\text{N}_{SW} \tag{14}$$

$$PL_R \times (x_2) \leq U\text{P}_{SW} \tag{15}$$

Where; NL_R = kg of N lost in runoff per kg of N applied

UN_{SW} = allowable upper limit of N in surface water

PL_R = kg of P lost in runoff per kg of P applied

UP_{SW} = allowable upper limit of P in surface water

(ii) Ground water pollution control

$$NL_{DP} \times (x_1) \leq U\text{N}_{GW} \tag{16}$$

$$PL_{DP} \times (x_2) \leq U\text{P}_{GW} \tag{17}$$

Where; NL_{DP} = kg of N lost in deep percolation per kg of N applied.

UN_{GW} = allowable upper limit of N in ground water

PL_{DP} = kg of P lost in deep percolation per kg of P applied.

UP_{GW} = allowable upper limit of P in ground water

2.9. Development of the Decision Support System (DSS)

The objective of reducing non-point source pollution of water resources could be achieved by a Decision Support Systems (DSS) that can store base data, simulate pollutant transport and help human operators in identifying effective management practices. The DSS was developed to (a) estimate the runoff, sediment and nutrient transport from an agricultural watershed (b) determine the nutrient balance within the root zone and leaching beyond root zone (c) determine the limiting rate of fertilizer application (N and P) that would facilitate a sustainable yield minimizing pollution of surface and ground water. The Decision support system for agricultural nonpoint source pollution control (DSS-ANSPC) consisted of three modules such as: Surface Transport Module, Sub-Surface Transport Module and Optimization Module.

3. RESULTS AND DISCUSSION

3.1 Analysis of sediment yield

Sediment loss from the Kapgari watershed was monitored during the monsoon season (June–October) of the year 2002, 2003, and 2004. Temporal variation of sediment yield with rainfall for the whole watershed for the year 2004 has been shown in Figure 2. From the figure, it is

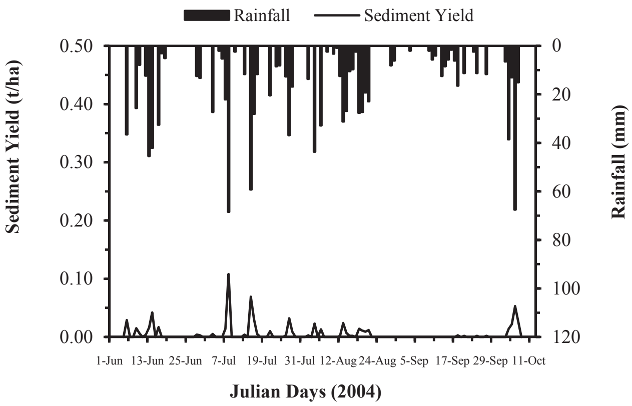

Figure 2. Observed sediment yield for the main outlet of Kapgari watershed.

seen that the peaks of the sediment yield matched well with that of the rainfall event for Kapgari watershed. It was also observed that the sub-watershed-III have the highest sediment followed by sub-watershed II and sub-watershed-I, which is due to the undulating topography. A major portion of this sub-watershed consists of barren land, which might have contributed to soil loss. Contribution of sediment yield from sub-watershed-II is higher as compared to sub-watershed-I due to the fact that this sub-watershed constitutes degraded forestland as well as settlements. However, the sub watershed-I has the lowest sediment yield due to the presence of bunded rice fields, in which sediments get deposited.

3.2 Analysis of water quality

Nutrient loss from Kapgari watershed was monitored during the same periods. The water samples were taken from the outlets of sub-watersheds and from the main outlet. NO_3-N and P concentrations in the water samples were determined using the Ion-chromatography systems. Temporal variation of nutrient loss for the whole watershed during 2004 is shown in Figs 3 and 4. From the figures it is seen that sub watershed I of Kapgari watershed contributed more nutrient loss compared to sub-watershed II and III due to the more area under rice cultivation and higher amount of fertilizers application.

3.3 Nutrient balance components

The nutrient balance components comprising of applied fertilizer N, fertilizer used by the plant, leaching loss and nitrogen depletion (denitrification, decomposition, volatilization, and erosion) from the root zone of all the crops under unsaturated crops such as wheat, potato, and peanut under the different irrigation and fertilizer treatments were analyzed. The nutrient balance components of the rice crop under saturated condition for the various irrigation and fertilizer treatments in the period of 2002–2005 shows that the leaching of nutrient N and P noticeably increased with

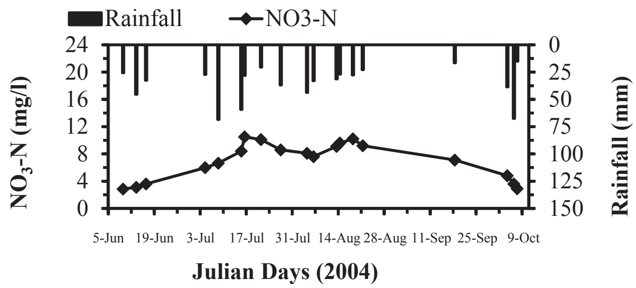

Figure 3. Observed NO_3-N loss for the main outlet of Kapgari watershed.

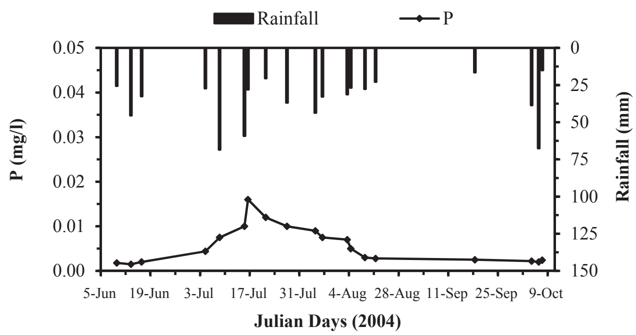

Figure 4. Observed P loss for the main outlet of Kapgari watershed.

the increase in fertilizer application and leaching of nutrients was more in case of frequent application of irrigation. It was found that increasing the application rate of fertilizer increases the leaching amount. The amount of leaching was found to be the highest in case of F_4 treatment, whereas lowest amount was obtained in case of F_2 treatment. The amount of leaching for different rates of fertilizer applications followed the trend $F_4 > F_3 > F_2 > F_1$. Whereas, the amount of leaching decrease by increasing in MAD level for wheat, peanut and potato crops. The amount of leaching followed the trend $I_1 > I_2 > I_3$ under different irrigation scheduling by similar rate of fertilizer applications. The leaching amount was found to be more for I_1 treatment by frequent irrigation and decreased by increasing in MAD level. It was also found that the initial split of N fertilizer increases the N use rate by plant initially. Therefore, the I_1F_4 treatment has maximum N-leaching for all the three crops. The nitrogen use increased in order to increase in fertilizer quantity ($F_4 > F_3 > F_2 > F_1$). Whereas, the nitrogen use decreased by increasing the level of MAD ($I_1 > I_2 > I_3$). Hence, the nitrogen use by the plant was found to be maximum under I_1F_4 treatment which is the same as the amount of leaching.

3.4 Salient findings of the controlled study in the field plots and lysimeters

1. Leaching study in the controlled field plots revealed that scheduling of irrigation based on 10% MAD of ASW results in higher leaching losses of nutrients than that based on 40% and 60% MAD of ASW.

2. Water and fertilizer use efficiency of all the crops were found to be maximum for scheduling of irrigation at 40% MAD (I_2) with F_2 fertilizer treatment (Panda et al., 2003).
3. HYDRUS 2D model predicts the nitrogen (NO_3-N) and phosphorus (PO_4-P) concentration in different soil layers for all the crops with a considerable accuracy.
4. Lysimetric study in the controlled field plots revealed that the $NO_3$and PO_4 concentrations beyond root zone are higher than the permissible limits whereas atrazine is within permissible limits in treatments I_1F_3, I_1F_4 and I_1F_2 respectively.

3.5 Salient findings of soil column study

1. Malathion and Atrazine are influenced by solute flow rates in column study. Both appeared early in faster flow rates.
2. Early breakthrough in a fast flow rate for Malathion was obtained in sandy loam soil. This suggests that faster mobility of water in column provided lesser time for retention of pesticides.
3. Malathion degrades faster and leaches slower than atrazine. Therefore it can be considered safer for application and use in Indian climates than atrazine. However under faster flow rates there was considerable leaching of Malathion. This requires greater attention when used in lighter textured soils in high rainfall area.

3.6 Results of optimization module

After running the surface and subsurface transport modules (watershed scale), the optimization module was run on the same window. The Objective function was

$$Y = 0.0047 \times (x_1 + x_2 + x_3) + 2.5694 \qquad (18)$$

Where Y is the yield (tons/ha), x_1, x_2 and x_3 are the amount of N, P and K applied in kg/ha respectively, 0.0047 is the yield of crop per unit consumption of fertilizer mixture in ton/kg and 2.5694 is the yield at any application of fertilizers in ton/ha.

Constraints:

1. In case of fertilizer constraint related to the yield, the lower limits of N and P were considered to be 80 and 40 kg/ha respectively and the higher limits of N, P, and K were considered to be 180, 140 and 130 kg/ha respectively.
2. In case of fertilizer constraints in relation to pollution control, 0.09 kg of N is lost in runoff per kg of N applied, 8.514 is allowable upper limit of N in surface water, 0.01203 is kg of P lost in runoff per kg of P applied and 0.5014 is allowable upper limit of P in surface water.
3. For groundwater pollution control, 0.227 kg of N lost in deep percolation per kg of N applied, 27.2 is allowable upper limit of N in ground water, 0.0396 is kg of P lost in deep percolation per kg of P applied and 1.9172 is the allowable upper limit of P in groundwater.

Having set the objective function and constraints, the optimization module was run and the limiting rate of Nitrogen (N), Phosphorous (P), and Potassium (K) was found to be 95 kg/ha, 42 kg/ha and 40 kg/ha respectively.

3.7 Salient findings of the optimization and Decision Support System (DSS)

The conclusions drawn through the results obtained by single-objective linear programming techniques are as follows:

1. Application of fertilizers in the rainfed crop (rice) causes loss of nutrients through runoff and deep percolation that leads to surface as well as groundwater pollution.
2. Results from the Optimization module showed that 95: 42 kg/ha (N: P) is the limiting level of fertilizer for rainfed rice when maximization of yield is the single objective and minimization of pollution is the constraint.
3. DSS-ANSPC simulates the loss of nutrients (N and P), in addition to runoff and sediment yield, reasonably well. The results of DSS-ANSPC show that the modules perform satisfactorily for the entire watershed and for the sub-watersheds independently. The DSS-ANSPC can effectively be used for other locations with suitable calibration.

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